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Production and economics of native pecan silvopastures in central United States

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Abstract

Riverine silvopastoral practices with native pecan (*Carya illinoinensis*) are a suitable land use for areas subjected to seasonal flooding in southern and central regions of the United States. Nut, timber and forage production, and the economics of managed pecan silvopastures were examined in southeastern Kansas. During 1981–2000, annual hulled nut production varied between 50 and 1600 kg ha^{-1} in stands averaging 72 years of age, and ranging in density between 35 and 74 trees ha^{-1}. The nut crop had a pattern of biennial bearing with some exceptions. Tree stem diameter and stand basal area increased linearly with time. Nut production was not related to stand age or tree density, however, suggesting that nut production had reached a steady state level. Merchantable timber yield ranged between 0.25 and 1.35 m^3 ha^{-1} year^{-1}. In pecan silvopastures with a mean tree age of 37 years, forage production varied between 1500 and 4600 kg DM ha^{-1} in 2001 and 2002. In 2001 only, grass production decreased with decreasing solar radiation within the range of 0.25–0.83 of fraction light transmitted. In both years, the grass understory had acceptable quality for cow-calf production with average crude protein content between 9 and 11.8%, and no evidence of excessive levels of ergoalkaloids from tall fescue. Twenty-seven vascular plants were identified in the understory of which nut sedge (*Cyperus esculentus*), tall fescue (*Festuca arundinacea*), wild oat (*Avena fatua*) and Canadian wild rye (*Elymus canadensis*) were the most abundant. Economic simulations obtained with the U.S. Agroforestry Estate Model indicated that pecan nut price is the main variable driving economic outputs under current production conditions. Annual cash flows from nut sales had smaller fluctuations than nut yields because of an inverse relation between nut price and yield. Improved timber production appears an option for increasing profitability of pecan silvopastures.

Introduction

The combination of native trees with pastures can be at least as productive, and more resilient and biologically diverse than schemes with introduced tree species. Silvopastures could produce greater return than traditional ranching or forest enterprises (Clason 1995), and provide supplementary benefits such as reduced P runoff and increased C sequestration (Stainback et al. 2004). Profitability of silvopastures can improve by adding revenues from hunting rights (Grado et al. 2001) and household payments for enhanced environmental quality (Shrestha and Alavalapati 2004).

Silvopastoral practices are particularly worthy of preservation in areas subjected to periodic floodings. In the United States, one of the most common native agroforestry practice is the association of pecan (*Carya illinoinensis* (Wangenh) K. Koch) with grasses and livestock on flood plains. In the northern part of pecan's natural range (i.e., northeastern Oklahoma, southeastern Kansas and southwestern Missouri), such silvopastoral practices provide a large portion of the commercial pecan nut crop. This production comes almost entirely from native stands (Reid and Hunt 2000). In pecan silvopastures, the herbaceous understory prevents soil losses, and controlled grazing reduces mowing costs while revenues from livestock and timber improve cash flows.

Pecan nut yields from northern native stands have been documented (Reid and Olcott-Reid 1985), but there is little information on forage and timber yields from pecan silvopastures as well as updated economic analysis of this land use. Important aspects of overall productivity and sustainability of the practice are pasture yields, nutritional quality of forages, and presence of factors in the herbage that may affect livestock health. The grass understory in pecan's northern range is likely a complex system because of the presence of native, introduced and naturalized grasses in a transitional climatic area. The presence of tall fescue (*Festuca arundinaceae* Shreb) in pecan silvopastures calls attention to the possible incidence of fescue toxicosis among grazing animals if the tall fescue is infected with the endophyte fungus *Neotyphodium coenophialum* (Glenn, Bacon, Hanlin). The fungus produces alkaloids that adversely affect cattle while conferring drought and pest resistance to the grass.

Timber production in pecan silvopastures is often neglected despite pecan's wood use for cabinetmaking, paneling, furniture and flooring (Arno 1991). Most pecan timber comes from tree thinning aimed at reducing overcrowding to sustain nut production. A fundamental step toward improvement in the management of the timber resource in pecan silvopastures is the determination of standing stocks and annual increments, thus enabling derivation of potential extraction rates.

The economics of native pecan silvopastures will largely determine the continuity and adoption of this land use option. There is concern that profits from native pecan groves have been decreasing over the past 20 years (Reid 1990). Pecan nut prices adjusted for inflation have declined since 1977, but production costs have increased dramatically (Reid 1991; Wood 2001). With sound input data, simulation tools such the U.S. Agroforestry Estate Model, USAEM (New Zealand Forest Research Institute 1994), are useful for examining the economic fitness of agroforestry practices.

Knowledge gained from a systemic study of pecan silvopastures may promote the continuity of this land use by suggesting management alternatives to improve financial results. Specific objectives of this study were to: (1) define trends in nut yields over time, (2) develop predictive functions to determine timber yields, (3) assess production, quality and diversity of the understory forage resource, and (4) examine profitability of pecan silvopastoral practices under different scenarios.

Materials and methods

Study area

We conducted this study in pecan stands on the floodplains of the Neosho River, near Chetopa, in southeastern Kansas (37° N latitude, 95° W longitude). The climate is typically continental, with cold winters and hot summers. Average annual rainfall in Columbus, Kansas at 32 km of the experimental site is 1030 mm and average annual temperature is 14.2 °C. The growing season spans from early April to late October with 200 frost-free days.

Nut production and tree growth

Nut yield by plot and tree stem diameter at 1.37 m (DBH) of each tree within a plot were measured from 1981 to 2000 in six 0.2 ha plots (site 1), which included only native pecan trees in the overstory. The soil is a fine, montmorillonitic, thermic Vertic Haplaquoll, Osage series (Soil Survey Staff 1992). Tree age obtained by ring counting in 2002 ranged between 59 and 84 years (mean = 72 years).

Pecan is ring porous, thus rings are well defined and easily visible for age estimation (Stokes et al. 1995). Tree density declined from 39–202 trees ha^{-1} in 1981 to 35–74 trees ha^{-1} in 2000, as the result of selective thinnings.

In 2001, outside-bark trunk diameters of 49 standing trees in site 1 were measured at 0.30, 1.37, 2.74, 3.95, and 5.48 m by an operator mounted on a self-propelled hydraulic bucket. Diameter measurements were restricted to the main tree bole, which constitutes the most valuable portion for timber. Thirty-seven trees had single trunks and 11 trees forked at heights between 2.9 and 4.1 m. Stem diameter ranged between 0.37 and 0.84 m. High quality pecan sawlogs at least 2.74 m long and 0.40 m in diameter are used for furniture while small diameter logs are mostly used for pallets and firewood.

Data from standing trees were used to develop volume and taper functions. We generated an equation to predict bole volume (V, m^3) with bark above a 0.30 m stump as a function of stem diameter at 1.37 m above ground (DBH, m) and bole height (H, m):

$$V = a_1 \mathrm{DBH}^{a_2} H + \varepsilon, \tag{1}$$

where a_1 and a_2 are model coefficients, and ε is the error of estimation. A similar equation was fitted for forked trees with H being height to the fork in m.

A taper equation (Kozak et al. 1969) also was derived for further calculation of wood volume for any merchantable size:

$$d^2 \mathrm{dbh}^2 = b_1 + b_2(h/H) + b_3(h^2/H^2) \tag{2}$$

where d is diameter in m at a given height h, and b_1, b_2 and b_3 are model coefficients.

Pasture production, quality and composition

We examined forage production, quality and composition in two separate sites (sites 2 and 3) representing operational conditions of pecan silvopastures. These sites were also on Osage series soil at less than 3.2 km from site 1. Site 2 had 43 trees ha^{-1}, average tree age of 38 years, mean DBH of 54 cm and mean stand basal area of 9.9 m^2 ha^{-1}. Site 3 had 41 trees ha^{-1}, average tree age of 36 years, mean DBH of 54 cm and mean stand basal area of 9.5 m^2 ha^{-1}. Nut yields in sites 2 and 3 had been similar than those in site 1.

Forage yields were determined at site 2 in 2001 and 2002, and only in 2002 at site 3. In each site, four 5.9 m^2 exclosures were built with 1.2 m-tall cattle panels across three N–S transects for a total of 12 plots per site. In each transect, we selected three solar radiation environments: one low ($<$0.45 fraction light transmitted, FLT), two intermediate (from 0.45 to 0.75 FLT), and one high ($>$0.75 FLT). In early June of 2001, FLT was measured in early morning or late evening with a digital plant canopy analyzer (CI-110, CID Inc., Vancouver, WA, USA). Forage was cut at 5-cm above-ground with a 0.9 m-wide sickle mower in spring and late summer (May and mid-September). Herbage yields were used to estimate potential forage growth during the period of grazing (Williams et al. 1999). Forage harvests provide estimates of forage yields but may not reflect true productivity under grazing because of differences in shading, plant maturity and plant development, resulting from continual forage removal by grazing animals.

Forage samples from each exclosure and sampling time were dried at 65 °C to constant weight and ground to pass a 1-mm sieve. Nitrogen was determined by combustion and crude protein was calculated by multiplying percent N by 6.25 (Goering and van Soest 1970). In vitro dry matter digestibility (IVD) was determined by the procedure of Goering and Van Soest (1970) modified for the ANKOM Daisy II digester (ANKOM Tech. Corp., Fairport, NY). The ANKOM 200 fiber analyzer was used to determine both acid (ADF) and neutral (NDF) detergent fiber. Ergovaline content as an indicator of the potential for fescue toxicosis among grazing animals was determined by HPLC (Craig 2000) at the College of Veterinary Medicine of Oregon State University.

A wooden one-m^2 frame, divided into 40 equal square areas, was randomly set inside each enclosure. Plant cover was assessed in each square and plant abundance was determined by counting the frequency of plant species on intersections of the interior lines of the wooden frame. Species richness (SR) was calculated as:

$$\mathrm{SR} = s + 0.975/k \tag{3}$$

where s = number of species in the 40 quadrats and k = number of species that occur in only one quadrat (Williams et al. 1999).

For forage data, the interaction FLT by transect was not significant at $p < 0.05$ and, therefore, FLT values for individual plots were regressed against forage yield and quality indices. Normality of data and residuals were examined by Lilliefors' test (Dallal and Wilkinson 1986). We compared forage yield, quality and composition between spring and summer, and between years with paired *t*-tests. The SAS statistical package (SAS 1992) was used for all analyses.

Economic analysis

The base agroforestry scenario was a silvopasture with 100 mature pecan trees more than 50 years old per hectare. Three insecticide applications are made annually on pecan trees. The first application is aimed at the pecan nut casebearer (*Acrobasis nuxvorella* Neunzig) while the other applications target the pecan weevil (*Curculio carvae* (Horn)), and the hickory shuckworn (*Cydia caryana* (Fitch)). Ground application, as used in this study, is a superior treatment method to aerial applications, but costs are approximately double because of higher labor and equipment expenses.

The understory of pecan stands is mowed and raked before nut harvest and after livestock removal. The relationship between nut production and harvest costs is linear above a nut yield of 230 kg ha^{-1}. During high-yield years, harvest cost drops slightly but a large harvest does not affect cleaning costs per unit nut weight. Surface drainage was improved initially after native forest clearing and every 10–15 years after that. Nitrogen is applied as urea at a rate of 114 kg ha^{-1} just before bud-swell. Nut yields for 'on' and 'off' years were the average yields from the plot measured from 1981 to 2000.

Nut price was \$1.36 (U.S.) per kg as the regional average for the 1993–2002 period. A price differential of $\pm 20\%$ was assigned to 'on' and 'off' years. Timber yields (0.5 m^3 ha^{-1} yr^{-1}) were from thinnings at 5, 10, 15 and 20 years. Timber price was \$125 (US) per m^3. This price is a representative 10-year average of pecan timber sales in the study region. Prices for low-quality pallet wood, dimensional lumber and veneer quality wood are 49, 134 and 223 \$ per m^3, respectively.

The livestock component was a cow-calf operation, as common in northern pecan silvopastures, with an animal carrying capacity of a cow-calf pair every 1.6 ha from April until the forage supply is exhausted, or the second half of September. Livestock were then taken outside the pecan orchards and fed with hay. Livestock gain was assumed to be 165 kg ha^{-1} $year^{-1}$ (Gadberry 1999). Livestock price was \$1.45 (US) per kg (1993–2002 average). The cow-calf enterprise budget was prepared following Gadberry (1999).

We used USAEM to estimate net present value (NPV) and discounted cash flows during a 20-year simulation. To calculate NPV, net incomes from each year were discounted to the current year using predetermined interest rates. Then, NPV was used to compare different investment scenarios over equivalent time periods and interest rates while cash flows reflected the liquidity of the scenario being studied (Godsey 2001). Regional information was compiled to estimate variable costs for nut, livestock, and timber production (Table 1). Appraised value of a pecan grove was \$2100 (US) per ha and annual property taxes were \$56.25 (US) per ha. Opportunity costs (OC) were calculated as an annual equivalent, OC = land price $(i\ (1+i)^{20}/(1+I)^{20}-1)$, where i = interest rate. Stand establishment costs were not included because the conversion of a riverine hardwood forest into a silvopasture is usually a break-even operation (W. Reid, personal observation). Timber sales pay for thinning, stump grinding or shearing, brush burning, ground leveling and establishment of a permanent ground cover. We calculated NPV and cash flows for different interest rates (4, 6 and 8%) and four agroforestry scenarios: (i) nut + beef production, (ii) nut (with 30% increase in nut price above average) + livestock, (iii) nut + livestock (with 30% gain in beef production efficiency), and (iv) nut + livestock + timber production.

Results

Rainfall

During the period when forage yields were measured, annual rainfall was 994 and 950 mm in 2001 and 2002, respectively. Rainfall was more uniformly distributed in 2002 than in 2001 (Figure 1). There was more rainfall in late spring (June) and fall (September–December) in 2001 compared to 2002 (Figure 1).

Table 1. Costs for pecan silvopastoral practices in southern Kansas.

Item	Cost ($ US)
Nut production	
Insecticide applications	112.5 ha^{-1}
Mowing and raking	20.0 ha^{-1}
Harvest and cleaning	0.55/nut kg
Surface drainage improvement	2.5 ha^{-1}
Fertilizer	41.3 ha^{-1}
Livestock production	
Animal health	48.9 ha^{-1}
Hauling/Freight	4.7 ha^{-1}
Sale commission	10.5/livestock unit
Herbicide	4.1 ha^{-1}
Hay	50.0 ha^{-1}
Timber production	
Logging	3.1/m^3

Costs are annual except for drainage improvement and logging that take place periodically.

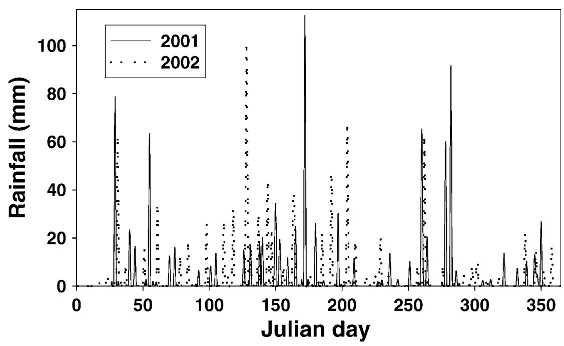

Figure 1. Rainfall distribution during 2001 and 2002 at the Pecan Experimental Field, Chetopa, Kansas.

Nut production

During 1981–2000, average nut yields in site 1 varied between 67 and 1202 kg ha^{-1} $year^{-1}$. Individual plots yielded as low as 50 kg ha^{-1} $year^{-1}$ and as high as 1600 kg ha^{-1} $year^{-1}$. The pattern of nut bearing was usually biennial with some exceptions (Figure 2). The biennial bearing pattern was not followed in 1988 and 1993 with exceptional low yields in 1990 which were caused by cold injury in 1989 that prevented flowering the next year (W. Reid, personal observation). Nut production was less than average in 1995 and 1996. Average nut yield was 361 kg ha^{-1} $year^{-1}$ (standard error = 56.5) in 'off' years and 833 kg ha^{-1} $year^{-1}$ (standard error = 70.3) in 'on' years.

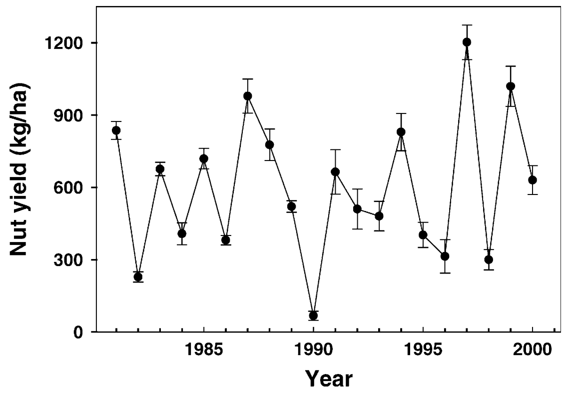

Figure 2. Pecan nut production from 1981 to 2000 at the Pecan Experimental Field (site 1), Chetopa, Kansas. Values are means ± one standard error.

Tree growth and timber yield prediction

Stem diameter increased linearly at an average annual rate of 0.8 cm. Nut production did not increase over time despite increases in tree diameter and stand basal area.

The equation to estimate wood volume of pecan trees as a function of DBH (m) and H (m) was:

$$\begin{aligned} &V = 0.6134\ \mathrm{DBH}^{1.7775}\ \mathrm{H}, \\ &\text{residual mean square (RMS)} = 0.007, \\ &\text{percent explained variance (PEV)} = 99.6. \end{aligned} \tag{4}$$

The taper function was:

$$\begin{aligned} &d^2hbox/DBH^2 1.80671 - 2.69828(h/H) \\ &+1.51822(h^2/H^2), \mathrm{RMS} = 0.036,\ \mathrm{R}^2_{dj\cdot} = 0.81 \end{aligned} \tag{5}$$

where d is diameter at a given height h and H is top height. From Equation (2), upper stem diameter can be estimated as:

$$\begin{aligned} d = \mathrm{DBH}(&1.80671 - 2.69828(h/H) \\ &+ 1.51822(h^2/H^2))^{1/2} \end{aligned} \tag{6}$$

and the height at a specified diameter as:

$$\begin{aligned} h = (&2.69828H - ((-2.69828H)^2 \\ &- 6.07288\{1.80671H^2d^2H^2/\mathrm{DBH}^2\})^{1/2}) \\ &/3.03644 \end{aligned} \tag{7}$$

(Avery and Burkhart 1994).

The equation to estimate wood volume of forked pecan trees as a function of DBH (m) and height to the fork bole (Hf, m) was:

$$V = 7.0374\ \mathrm{DBH}^{2.1250}\ H^{-0.4043}$$
$$\mathrm{RMS} = 0.012,\ \mathrm{PEV} = 99.4. \quad (8)$$

Using Equations (4) to (8), we calculated that 7.4 m^3 were removed in thinnings from the 1.2-ha area in site 1 from 1981 to 2000. Timber (up to 5.48-m log length) production during the same period ranged between 0.23 and 1.35 m^3 ha^{-1} $year^{-1}$.

Pasture yield, quality and composition

Forage yields ranged between 1530 and 2280 kg Dry Matter (DM) ha^{-1} in 2001, and between 2500 and 4570 kg DM ha^{-1} in 2002 (Table 2). There were no significant differences in forage yields among transects. When pasture yields for individual enclosures were regressed against FLT, a positive relationship was observed both in spring and late summer in 2001 (r = 0.65 and 0.68, respectively; $p = 0.02$ for both seasons). For both sites, forage yield in spring was greater than in late summer ($p < 0.001$). In site 2, forage yield in 2002 was higher than in 2001 in spring ($p < 0.001$) but not in late summer. Site 3 was more productive than site 2 in 2002 ($p = 0.01$) probably because of slighter better drainage.

Forage had acceptable quality for cow-calf production (National Research Council 1984) as indicated by average crude protein content (9–11.8%), IVD (49–70%), NDF (52–81%) and ADF (34–60%) (Table 2). In individual plots, protein content had absolute low and high values of 7.3 and 12.6%. In general, forage quality indices were not related with FLT except for the negative relationship with IVD ($r = -0.80$, $p = 0.02$) and the positive one with DF ($p = 0.04$) in the late summer sampling in 2001.

Average ergovaline contents were lower than 10 μg kg^{-1} in site 2 in 2001, and 75 μg kg^{-1} in both sites in 2002. These low levels of ergovaline indicate that the incidence of fescue toxicosis among grazing cattle should be low. Toxicosis is induced in cattle when ergovaline levels in forage exceeds 400–750 μg kg^{-1} (Tor-Agbidye et al. 2001).

Twenty seven species of vascular species were found in the understory. The most common were nut sedge, tall fescue, wild oat and Canadian wild rye (Tables 3 and 4). A group of 19 species averaging at least 5% abundance in the different solar radiation regimes included eight introduced forages (tall fescue, red fescue, ladino clover, white

Table 2. Forage yield and quality in spring and late summer samplings of pecan silvopastures in southern Kansas.

Radiation regime		Yield (kg ha^{-1})	Protein (%)	IVD (%)	NDF	ADF (%)
Spring						
Low (< 0.45 FLT)	Site 2 2001	600 ± 40	9.9 ± 0.6	62.4 ± 2.0	76.9 ± 0.7	55.8 ± 0.7
	Site 2 2002	2030 ± 189	10.6 ± 0.5	49.8 ± 0.8	67.9 ± 1.5	42.6 ± 1.5
	Site 3 2002	1940 ± 50	10.0 ± 1.1	61.6 ± 0.7	64.7 ± 4.3	43.1 ± 4.2
Intermediate (0.45–0.75 FLT)	Site 2 2001	770 ± 81	9.2 ± 0.4	61.5 ± 1.8	79.2 ± 1.6	54.1 ± 1.1
	Site 2 2001	1770 ± 116	9.6 ± 0.3	52.7 ± 1.9	65.9 ± 0.8	43.0 ± 0.8
	Site 3 2002	2580 ± 229	9.4 ± 0.5	67.5 ± 1.5	55.7 ± 1.6	48.7 ± 1.7
High (> 0.75 FLT)	Site 2 2001	830 ± 152	9.8 ± 1.1	62.1 ± 2.1	81.1 ± 2.9	54.8 ± 1.8
	Site 2 2001	2060 ± 247	10.4 ± 0.9	53.0 ± 1.26	66.3 ± 2.5	42.6 ± 1.85
	Site 3 2002	3250 ± 924	8.6 ± 0.5	7.1 ± 1.2	51.9 ± 3.0	1.1 ± 2.5
Late summer						
Low (< 0.45 FLT)	Site 2 2001	880 ± 8.0	9.2 ± 0.3	57.8 ± 1.7	76.4 ± 2.1	57.0 ± 1.9
	Site 2 2001	720 ± 130	10.2 ± 0.9	48.9 ± 4.4	65.6 ± 2.4	34.4 ± 2.4
	Site 3 2002	790 ± 68	11.7 ± 0.5	57.4 ± 3.5	60.7 ± 1.4	42.1 ± 1.5
Intermediate (0.45–0.75 FLT)	Site 2 2001	1010 ± 128	9.0 ± 0.4	56.2 ± 0.6	76.1 ± 1.3	56.9 ± 0.8
	Site 2 2001	730 ± 100	9.7 ± 0.5	52.7 ± 3.8	66.0 ± 0.5	34.0 ± 0.4
	Site 3 2002	1510 ± 174	11.8 ± 0.3	56.9 ± 0.9	61.5 ± 0.6	41.3 ± 0.6
High (> 0.45 FLT)	Site 2 2001	1450 ± 319	9.2 ± 0.3	50.7 ± 1.5	78.2 ± 1.1	60.4 ± 1.5
	Site 2 2001	1160 ± 401	10.8 ± 0.4	52.5 ± 2.7	61.3 ± 3.1	44.5 ± 0.3
	Site 3 2002	1320 ± 393	10.4 ± 0.5	70.0 ± 1.7	55.1 ± 1.8	50.6 ± 2.4

Values are means ± one standard error. FLT = Fraction light transmitted, IVD = *In vitro* fiber digested, NDF = Digested neutral detergent fiber, ADF = Digested acid detergent fiber.

Table 3. Understory plant composition in pecan silvopastures in southern Kansas (site 2).

	May 2001						May 2002						Sept 2002					
Radiation regime	Low		Medium		High		Low		Medium		High		Low		Medium		High	
Plant species	C	A	C	A	C	A	C	A	C	A	C	A	C	A	C	A	C	A
Nut sedge (p, n)	55.0	54.2	50.2	50.9	90.8	89.2	41.6	44.8	21.7	17.1	2.7	2.5	80.2	80.8	78.0	77.4	39.4	39.5
Tall fescue (p, i)	13.4	17.5	39.0	36.9	1.7	1.7	6.5	8.3	23.2	26.5	4.4	3.3	6.6	4.2	9.2	8.8	1.7	2.5
Red fescue (p, i)	1.25	11.7					3.2	0.9	10.6	8.5	11.9	12.5						
Bermuda grass (p, i)	5.8	3.3	3.3	3.3	1.7	1.7									1.2	0.0		
Canadian wild rye (p, n)	5.0	3.3			0.0	0.8	4.0	1.7	11.1	13.2	29.3	27.8	0.0	0.0	0.9	1.3	1.7	0.0
Alsike clover (p, i)			0.8	1.7														
Red clover (p, i)			0.4	0.0														
Korean lespedeza (a, i)	0.8	0.8	0.8	0.8	5.8	6.6												
Iron weed (p, n)			3.3	2.1			0.0	0.0	1.7	0.9	3.5	3.0	2.5	2.5	4.6	3.8	28.0	28.8
American violet (a, n)	7.5	9.2	1.8	4.3									1.6	0.8	2.4	2.5	0.0	0.0
Prickly sida (a, n)			0.4	0.0									0.8	0.0	2.9	0.8	12.5	11.7
Violet woodsorrel (p, n)													0.0	0.0	0.0	0.0	1.7	1.7
Nightshade (p, i)													0.0	0.0	0.0	0.0	6.7	5.8
Dandelion (p, i)								0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.8	0.8	8.3	10.0
Cheat grass (a, i)								0.8	0.0	17.5	23.1	0.0	0.0					
Ladino clover (p, i)													0.0	1.7	0.0	0.8	0.0	0.0
White clover (p, i)													8.3	5.8	0.0	0.0	0.0	0.0
Curly dock (p, i)							0.0	0.0	0.0	0.0	0.7	0.0						
Wild oat (a, i)							38.4	42.7	7.3	8.1	44.8	46.7						
Wild onion (p, n)							2.4	0.0	3.2	0.0	0.0	0.0						
Bedstraw (a, i)							2.4	1.6	1.2	1.3	0.0	0.0						
Wild parsley (p, n)							0.7	0.0	1.7	1.3	2.7	4.2						

n = native, i = introduced, a = annual, p = perennial; C = cover, A = abundance.

clover, Korean lespedeza, wild oat, cheat grass, Bermuda grass), four introduced weeds (buck brush, curly dock, dandelion, nightshade), four native perennials (nut sedge, iron weed, violet woodsorrel, flowering spruge), and three native annuals (Canadian wild rye, American violet, prickly sida). Species cover and abundance were temporally and spatially variable and, in general, not related to FLT.

Species richness (SR) was not related to FLT and average SR varied between 3.7 and 7.6 in the different seasons. In late summer, SR was higher in 2002 than in 2001 ($p = 0.02$) but there were no differences between seasons within years, or between spring sampling in 2001 and 2002.

Economic analysis

Net present values for the nut + livestock production silvopastoral practice at current nut and beef prices were negative at interest discount rates of 6 and 8% indicating that the enterprise was not profitable (Table 5). An increase of 30% in nut price, however, markedly increased NPV to \$890–\$4402 depending of interest rate. This increment in NPV is higher than that obtained by increasing 30% beef production efficiency. Adding timber production to the nut + livestock production practice under current conditions also leads to positive NPV.

Cash flows for all scenarios were positive during the 20-year simulation (Figure 3). In silvopasture, cash flows under current price and cost conditions were \$365 per ha for 'off' years and \$435 per ha for 'on' years. A 30% increase of nut prices above current levels would raise cash flows to \$602–\$645 per ha. Adding timber production every five years increased cash flow to \$1145–\$1215 per ha in harvest years. Cash flows in scenarios with nut production did not oscillate as much as nut yields because of the inverse relation between nut yield and nut price.

Discussion

A mature native pecan grove on a representative site of the Neosho River floodplains in southern

Table 4. Understory plant composition in pecan ilvopastures in southern Kansas (site 3).

	May 2002						Aug 2002					
Radiation Regime	Low		Medium		High		Low		Medium		High	
Plant Species	C	A	C	A	C	A	C	A	C	A	C	A
Nut sedge (p, n)							13.5	10.9	14.2	15.0	20.8	18.1
Tall fescue (p, i)	66.8	71.9	40.5	37.0	61.8	49.1	15.9	10.8	24.6	21.2	15.0	10.8
Red fescue (p, i)	0.9	0.0	3.0	2.0	2.5	0.0						
Bermuda grass (p, i)		0.8	1.0	1.5						0.4		
Canadian wild rye (p, n)	2.6	4.2	0.5	0.0	1.8	2.5	4.2	6.6		0.8	0.8	
Alsike clover (p, i)												0.8
Red clover (p, i)	9.6	1.7	2.0	2.0								
Iron weed (p, n)	2.6	4.2	2.5	3.0	3.4	4.1	0.8	3.3	10.0	9.2	10.0	11.7
American violet (a, n)	0.8	0.0						1.5				
Prickly sida (a, n)							6.8	7.5	0.8	1.8	6.7	5.8
Violet woodsorrel (p, n)							15.0	17.5				
Nightshade (p, i)							26.9	15.0	2.1	3.3	1.7	1.7
Dandelion (p, i)	2.6	4.2	3.0	0.0	1.8	0.9			22.1	18.0	15.0	21.6
Cheat grass (a, i)	1.9	7.0	5.5	3.5	16.9	26.7			0.4		2.5	0.8
Ladino clover (p, i)							9.4	15.9		0.4		
White clover (p, i)							2.5	1.7				
Curly dock (p, i)	1.8	0.9	3.5	4.0	1.8	2.5	0.8	3.3	7.9	9.2	14.2	16.7
Wild oat (a, i)	4.4	0.9	37.0	46.5	10.0	14.2						
Wild onion (p, n)			1.5	0.5								
Bedstraw (a, i)	2.6	0.0										
Wild parsley (p, n)	3.4	4.2										
Buck brush (p, i)									10.0	11.0		
Bind weed (p, i)									2.5	2.3		
Flowering spruge (p, n)							4.2	5.0	5.4	6.5	13.3	12.0

n = native; i = introduced; a = annual, p = perennial; C = cover, A = abundance.

Table 5. Net present value for different discount rates, and pecan nut and wood prices in pecan silvopastures in southern Kansas.

Scenario	Interest discount rate		
	4%	6%	8%
Nut + livestock	885	(45)	(682)
Nut + livestock + timber	2840	1540	55
Nut (nut price = +30%) + livestock	4402	2982	1890
Nut + livestock (beef gain = + 30%)	1857	790	(70)

Values in parentheses are negative.

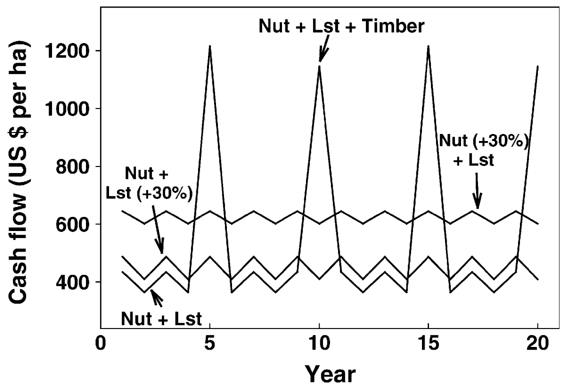

Figure 3. Cash flows for four production and price scenarios in silvopastoral practices in southern Kansas.

Kansas exhibited variable annual nut yields from 1981 to 2000. In-shell nut yields were slightly higher than those of native pecans in Texas (Stein and McEachern 1997), and about 50% lower than yields of irrigated orchards with selected varieties (Peña 1997). Tree stem diameter increased linearly but the overall trend and fluctuations in nut yields were not related to changes in tree size and stand basal area. Stand basal areas at sites 2 and 3 were about 20–30 % higher than the 7.4 m^2 ha^{-1} basal area considered optimum for pecan nut production in Oklahoma (Hinrichs 1958). It also has been empirically estimated that having 50% of the ground shaded (similar to the stands in this study) would be a good indicator of adequate stand density in native pecan groves (Stein and McEachern 1997) but further research is needed.

Forage yields under pecan were moderate (up to 4500 kg ha^{-1}) and greater in 2002 compared to 2001. Annual differences in forage production were associated with a more uniform distribution of rainfall during the growing season. Approximately 2200 kg of forage DM would be need to maintain a cow and produce a 165-kg calf using values of 1.3 and 0.6 kcal kg^{-1} of net energy for maintenance and growth, respectively (National Research Council 1984). Average annual forage yields measured in this study were similar to estimated needs described above. Efficient forage utilization will be required in most years to produce the calf at weaning.

Forage production of 6400 kg ha^{-1} has been reported for pecan silvopastures in southern Oklahoma (Mitchell and Wright 1991). In addition to management issues and site conditions, yield differences between those in this study and for southern Oklahoma can be attributed to differences in growing season and the forage species. In southern Kansas, a large fraction of the annual forage production results from cool season forages growing in the spring. In southern Oklahoma, pasture forage species include volunteer cool-season annuals in spring and, annual and perennial warm-season species in summer, with warm season forages comprising a greater portion of the annual herbage production.

The grass component under pecan trees possessed acceptable quality for livestock consumption. There was no evidence of fescue toxicosis during the two-year study. The understory was compositionally diverse in time and space. This diversity is likely beneficial for sustaining arthropods that control pecan pests (Bugg et al. 1991) and provide habitat and food for wildlife. The presence of certain species dominating scattered plots suggested considerable small-scale variation (e.g., patchiness in understory composition). Solar radiation levels under trees did not seem to greatly limit forage yield or regulate plant composition as plant species were widely distributed across the arbitrary set of radiation regimes established across the study area. This suggests that other factors such as below ground competition affects forage yields. Patterns of solar radiation reaching the ground of pecan orchards in Texas were found to be complex (Holt 1972). It is likely that a greater amount of light reaches the understory in native stands characterized by irregular tree distribution than in pecan orchards with regular tree distribution.

The profitability of the pecan silvopastoral practice is highly dependent upon nut price. Thus, a 30% increase in nut prices would increase NPV greater than four-fold over a 20-year period. Improved timber production appears to be an interesting alternative to improve revenues, especially if nut prices remain low. To fully capitalize on income from timber sales, trees would require more intensive management (pruning, reduction of tree damage from stand operations) and better marketing. Livestock gains could be increased by improved cattle management and forage resources through reseeding palatable species and reducing the most serious weeds. Increased revenues from livestock, however, would have a relatively low impact in the overall profitability of pecan silvopastures. In any case, pecan silvopastures will continue to suffer from fluctuations in cash flows (although partly predictable) because of the biennial nut production cycle. These alternate cash flows are smoothed by the inverse relation between nut price and yield.

Conclusions

The standard silvopasture practice involving native pecan in southern Kansas possesses desirable characteristics. These include low incidence of pecan pests (Reid and Hunt 2000), moderate production costs, sustained tree growth and forage resources of acceptable quality and quantity. Understory plant diversity likely contributes to increase system stability and resiliency, although forage resources could be improved through management practices aimed to reduce serious weeds and favor more palatable species. Annual variations in component production (nut, forage) is high because of biennial bearing pattern of pecan, and to a lesser extent, climatic effects on nut and forage components. So far, attempts to forecast nut production in southern Kansas have not been pursued and accurate predictions would aid investment and management decision making. Profitability of pecan silvopasture practices is primarily regulated by nut price and further decreases in nut prices could have serious consequences on this land use practice.

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Appendix. Scientific names of the species found in the understory of native pecan stands in Southeastern Kansas.

Alsike clover: *Trifolium hybridum* L.

American violet: *Viola sororia* Willd.
Bedstraw: *Galium aparine* L.
Bermuda grass: *Cynodon dactylon*(L.) Pers.
Bindweed: *Convolvulus arvensis*L.
Buck brush: *Symphiocarpus orbicularis*Moench.
Canadian wild rye: *Elymus canadensis* L.
Cheat grass: Bromus tectorum L.
Common ragweed: *Ambrosia artemisiifolia* L.
Crab grass: *Panicum glabrum*Gaudin
Curly dock: *Rumex crispus* L.
Dandelion: *Taraxacum officinale* Weber
Flowering spruge: *Euphorbia corollata* L.
Iron weed: *Veronia marginata* (Torr.) Raf.
Korean lespedeza: *Lespedeza stipulacea* Maxim.
Ladino clover: *Trifolium repens* L. var. ladino
Night shade: *Solanum nigrum* L.
Nut sedge: *Cyperus esculentus* L.
Prickly sida: *Sida spinosa* L.
Red clover: *Trifolium pratense* L.
Red fescue: *Festuca rubra* L.
Tall fescue:*Festuca arundinacea* Schreb.
Violet woodsorrel: Oxalis violacea L.
White clover: Trifolium repens L.
Wild Oat: *Avena fatua* L.
Wild onion: *Allium stellatum* Ker.
Wild parsley: *Lomatium foeniculaceum* (Nutt.) Coult. & Rose

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